A Coincidence Measurement of Electro-Production of Pions from Protons. (電子による陽子からの一中間子発生の同時計数法測定)

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論　文　内　容　要　旨

Coincidence measurement of the pion production in electron-proton collisions enables us to study the form factors of nucleon and pion.

The differential cross section of the reaction,

$$e + p \rightarrow e + p + \pi^0 \qquad (1)$$

has been measured by detecting the scatterered electrons and recoil protons simultaneously. The experimental arrangement is shown in Fig. 1. The electron beams were extracted from the Electron Synchrotron of the Institute for Nuclear Study, the University of Tokyo, and were analyzed and focused on a liquid hydrogen target. The extracted beam intensity was measured in an accuracy within one percent by a secondary emission chamber and a quantameter located at the rear of the target, and was found to be about 3 x 10^7 electrons per pulse, where the repetition was 21.5 cps. The energy spread and the fluctuation of electron energy was within one percent. The beam profiles were photographed and were found almost like an ellipse, which had the major axis of about 30 mm, and the minor of about 8 mm. The position and profile of the beams were checked during the course of experiment. The liquid hydrogen target was a cylinder of 10 cm long with diameter of 5 cm, and the wall of the vessel was made of 8 mil myler.

The secondary electrons scattered at the angle of 45 degrees were collimated by a Pb collimator, and were analyzed their momenta with an analyzer and, then detected with a counter telescope. The counter telescope consisted of three scintillation counters e_1, e_2, e_3, which had the dimension of 5.5" x 7.1" x 1/4", 10 cm x 15 cm x 0.5 cm, and 5.9" x 7.9" x 1/2", respectively, and of a Cerenkov counter, 30 cm long 20 x 20 cm^2 cross section. To eliminate low energy electron backgrounds, a copper absorber was inserted between e_2 and e_3. The efficiency of the Cerenkov counter for the electron was nearly 90 percent at the energy from 250 Mev to 400 Mev.

The resolution and the aperture of the whole electron counting system was calculated from a floating-wire measurement of the analyzer magnet, and the geometry of the collimator and the counter telescope. The solid angle was found to be 8.85 milli-steradians for a point source and the momentum resolution 6.4 percent.

The proton telescope was made of two large scintillation counters P_1, and P_2, which had the dimension of 30 cm x 32 cm x 0.5 cm, and 33 cm x 35 cm x 0.5 cm, respectively placed at 76 cm from the target, so that it had a large solid angle as described later.

For the purpose of over-all calibration of the detection system, the coincidence of elastically scattered electrons with recoil protons was measured for the incident electrons of 390 Mev. The proton telescope was placed at the angle most suitable from the kinematical consideration. The results are shown in

Fig. 2. Fig. 2 also shows the calculated spectrum, in which the cross section and the proton form factors obtained by many workers(1) were taken into account. The measured spectrum is in good agreement with the calculated one in shape wihin the statistical errors. By comparing the peak value of the measured spectrum with that of the calculated one, the solid angle and momentum dispersion of the analyzer could be derived for the inelastic process (1). From the ratio of the counting rate of scattered electrons only to that of e−p coincidences, the efficiency of the latter was determined to be 90 percent.

The cross section of the reaction (1) was measured under the following conditions :

Energy of incident electrons	E_1	593 Mev
Energy of scattered electrons	E_2	258 Mev
Scattering angle of electrons	θ_e	45 °
Recoil angle of protons	θ_p	42.5 °
Total energy of π^0 −P center−of−mass system		1190 Mev
Square of the four momentum transfer		2.29 F^{-2}

From the kinematical consideration, the region in the c. m. s. covered by the proton telescope is calculated and shown in Fig. 3, from which the c. m. s. solid angle of the telescope is estimated to be about 1.3 steradians.

Two resies of the experiments were made. Series I was done without absorber in front of the counter P_1 , and series II with a lead absorber of the thickness 5 mm in front of P_1 . The results are shown in Table I.

Table I. Experimental results of inelastic scattering

	Series I	Series II
No. of incident electrons	0.524 x 10^{13}	1.06 x 10^{13}
No. of scattered electrons	364	699
e − p coincidence counts	7	6
e − p accidental counts	4	0

It can be seen that the accidental counts were eliminated by inserting the lead absorber.

There are two competing processes which may mainly contribute to counting rate of e − P coincidences. The first one is the large angle bremsstrahlung(2) The contribution of this process was estimated to be (22 ± 8.9) percent in these experimental conditions. The second one is the reaction,

$$e + p \rightarrow e + n + \pi^+,$$

which was not eliminated because of the poor resolution of the proton telescope.

Under the plausible assumption that only the magnetic dipole interction is effective for neutral pion production, the cross section of the process (1) in the (3, 3) resonance region is estimated theoretically according to R. H. Dalitz and D. R. Yennie (3). The angular distribution and the differential cross section of neutral pions in the c. m. s. are shown to be the forms,

$$f(\theta, \Phi) = 5 - 3\cos^2\theta + \frac{4\varepsilon_1^2}{\lambda}\sin^2\Theta\,(1 + 3\sin^2\theta\sin^2\Theta)$$

and

$$\frac{d^2\sigma}{dE_2\,d\Omega} = \frac{4\alpha^2}{9\pi}\left(\frac{4\pi}{f^2}\right)\cdot\frac{E_2}{E_1}\cdot\frac{\mu^2}{EM\,|\mathbb{q}|^3}\cdot\frac{\mathbb{k}^2}{\lambda}\left(1+\frac{\omega}{M}\right)^2\left(1+\frac{2E_1^2}{\lambda}\sin^2\Theta_L\right)G^2{}_{mv}\quad\sin^2\delta_{33}$$

respectively, where θ, Φ are the angles defined in Fig. 3, Θ and Θ_L the virtual photon emission angle measured form the incident beam direction, in the c. m. s. and lab. s., ε_1 the incident electron energy, λ the four-momentum transfer squared of the electron, E the pion-nucleon total energy, $\mathbb{k}$ the virtual photon momentum, $\mathbb{q}$ and ω the meson momentum and energy, in the c. m. s. respectively, and G_{mv} is the isovector magnetic form factor, α the fine structure constant, f the pseudo vector pion-nucleon coupling constant, which is taken to be $\frac{f^2}{4\pi} = 0.073$, M and μ the nucleon and pion rest mass, δ_{33} the (3, 3) phase shift.

The theoretical cross section for neutral pion production (1) is thus

$$\frac{d^2\sigma}{dE_2\,d\Omega} = 3.92 \times 10^{-34}\ \mathrm{cm}^2/\mathrm{Mev.\,sterad.}$$

The experimental cross section for neutral pion production (1) is not directly obtained from the data, because of the contamination of the production (2) as decribed avove.

Assuming that the magnetic dipole, meson current and electric dipole interactions are effective for positive poin production (2), the amount of the contribution of this process into the e-p coincidences can be estimated to be 17 per cent of the counts corrected for the large angre bremss. term for Series 1 and 19 percent for Series 11.

Thus experimental cross section is obtained to be

$$\frac{d^2\sigma}{dE_2\,d\Omega} = (1.0 \pm 0.6) \times 10^{-34}\ \mathrm{cm}^2/\mathrm{Mev.sterad.}$$

Although any definite conclusion could not be drawn from the data because of very poor statistics, it seems possible that the theory could not give a satisfactory value of the cross section for neutral pion production.

In this connection it is to be noted that the cross section at the total energy of $\pi^0 - p$ center-of-mass system = 1.21 Bev and the square of the four momentum = $1.3F^{-2}$ measured by the Orsay group 4) is about a half of the prediction.

This experiment has been done by Professors Y. Kobayashi, S. Kaneko and Dr. Huke whom the author would like to thank for their guidances in this work, and Messers. T. Yamakawa, K. Baba, and the author. The author wishes to experess his gratitude to Professor T. Kitagaki for his leadership during the

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Thanks are also due to Mr. T. Takeda of the University of Tokyo for his helpful assistance during the course of experiment and the data analysis.

References :

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(2) E. A. Alton, Phys. Rev. 135 B 570 (1964)
(3) R. H. Dalitz and E. R. Yennie, Phys. Rev. 105, 1598 (1957)
(4) J. P. Perez Y Jorba, P. Bounin and J. Chollet, Physics Letters 11, 350 (1964)

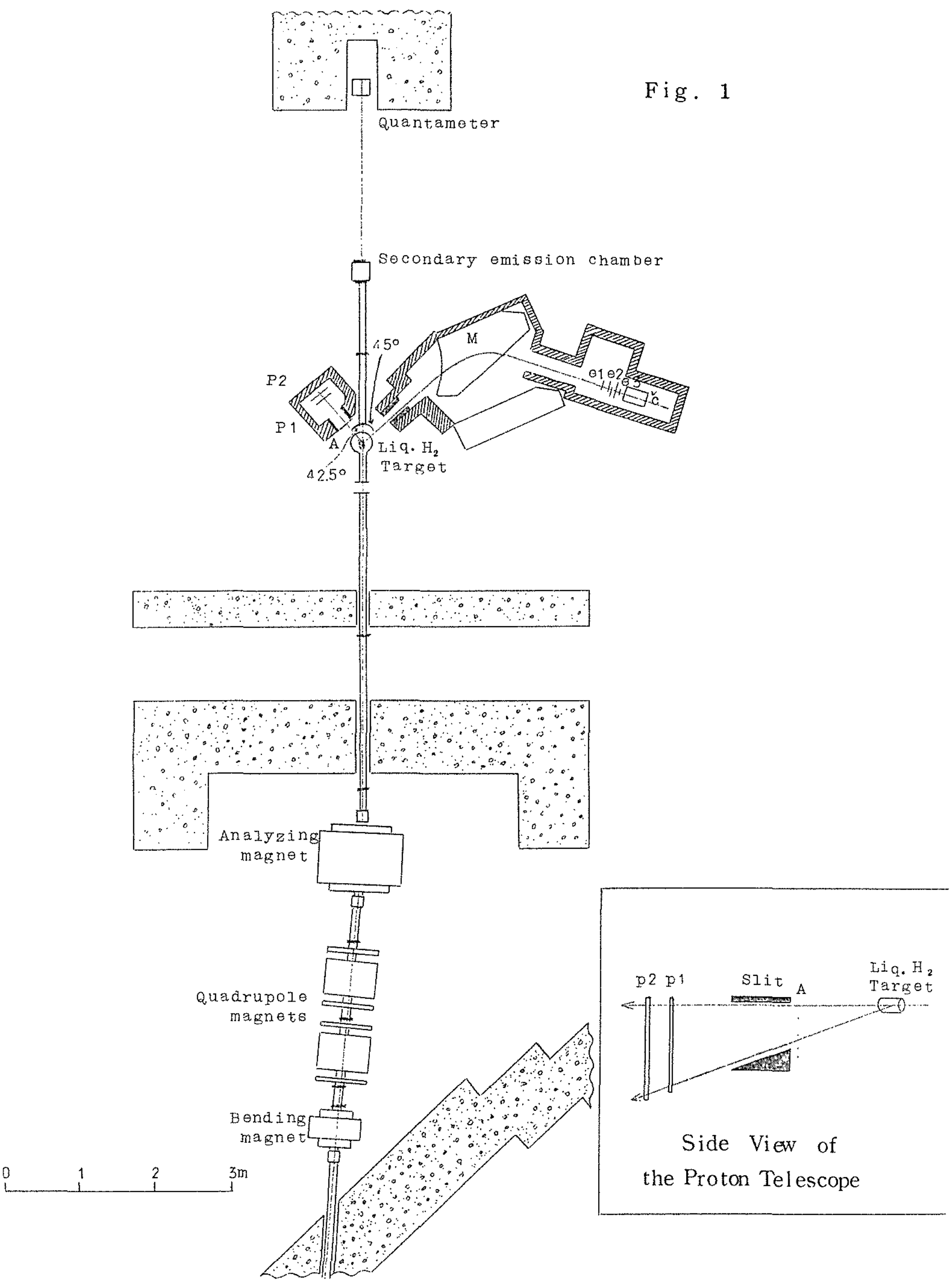
CAPTIONS FOR FIGURES

Fig. 1. Experimental arrangement

Fig. 2. Elastic scattering counts plotted against the secondary electron energy. Incident electron energy is 390 Mev, and electron scattering angle is 45°. The solid line represents the calculated curve based on the form factors given in ref. (1), and in this Figure is shown the absolute value multiplied by 0.7.

Fig. 3. The region in the c. m. s. accepted by thc proton telescope. The polar angle with respect to the virtual photon direction, and the azimuthal angle measured from the electron scattering plane, of the recoil proton in the c. m. s, are denoted by θ and ϕ, respectively. Shaded lines denoted by Series I and II represent the limiting polar angles in the case without and with lead absorber in front of the telescope, respectively.

Fig. 1


Quantameter
Secondary emission chamber
45°
M
P2
P1
A
e1 e2 e3
C
Liq. H_2
Target
42.5°
Analyzing
magnet
Quadrupole
magnets
Bending
magnet
0
1
2
3m
p2 p1
Slit
A
Liq. H_2
Target
Side View of
the Proton Telescope

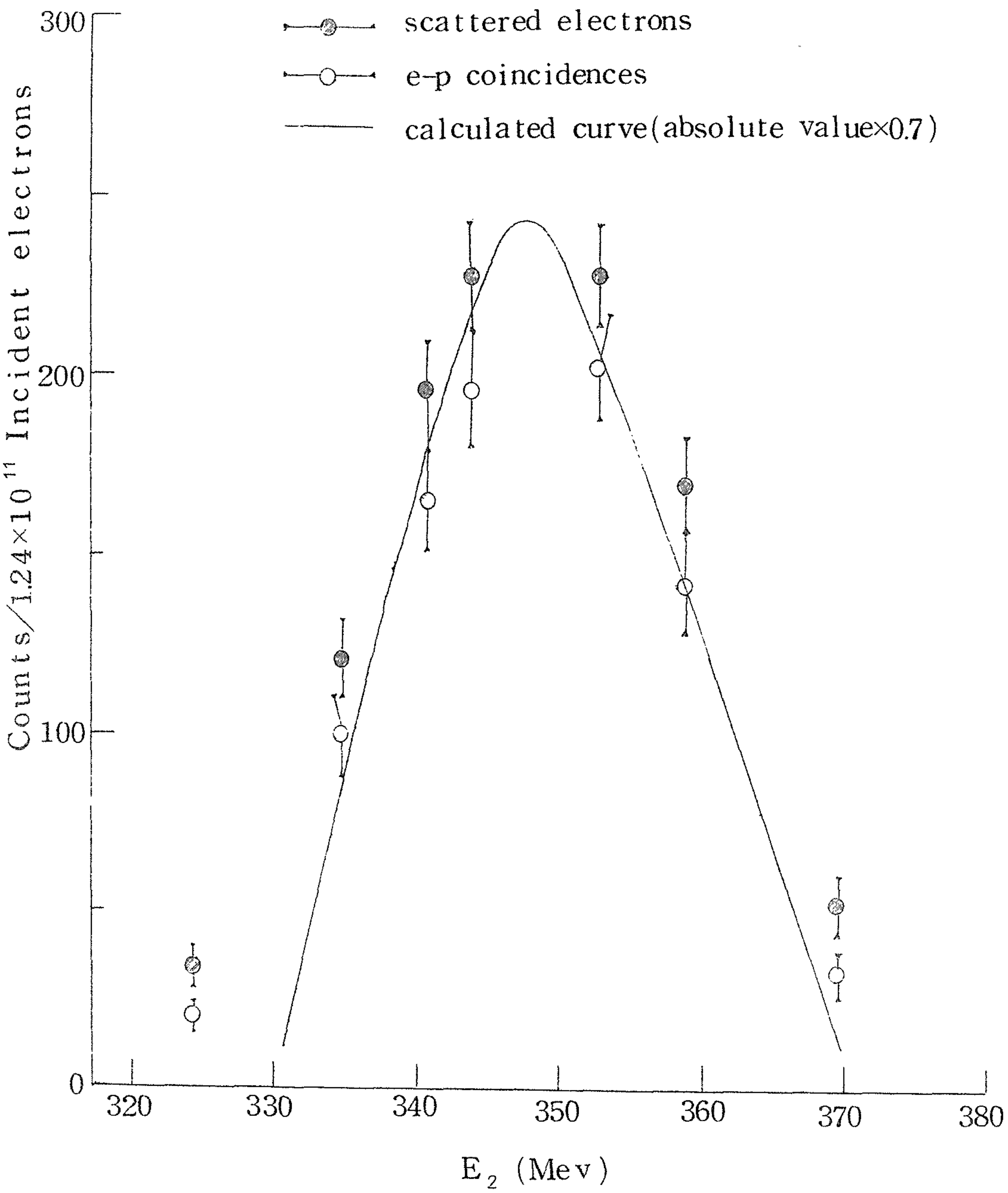

scattered electrons
e-p coincidences
calculated curve(absolute value×0.7)
Counts/1.24×10^11 Incident electrons
300
200
100
0
320
330
340
350
360
370
380
E_2 (Mev)

Fig. 2

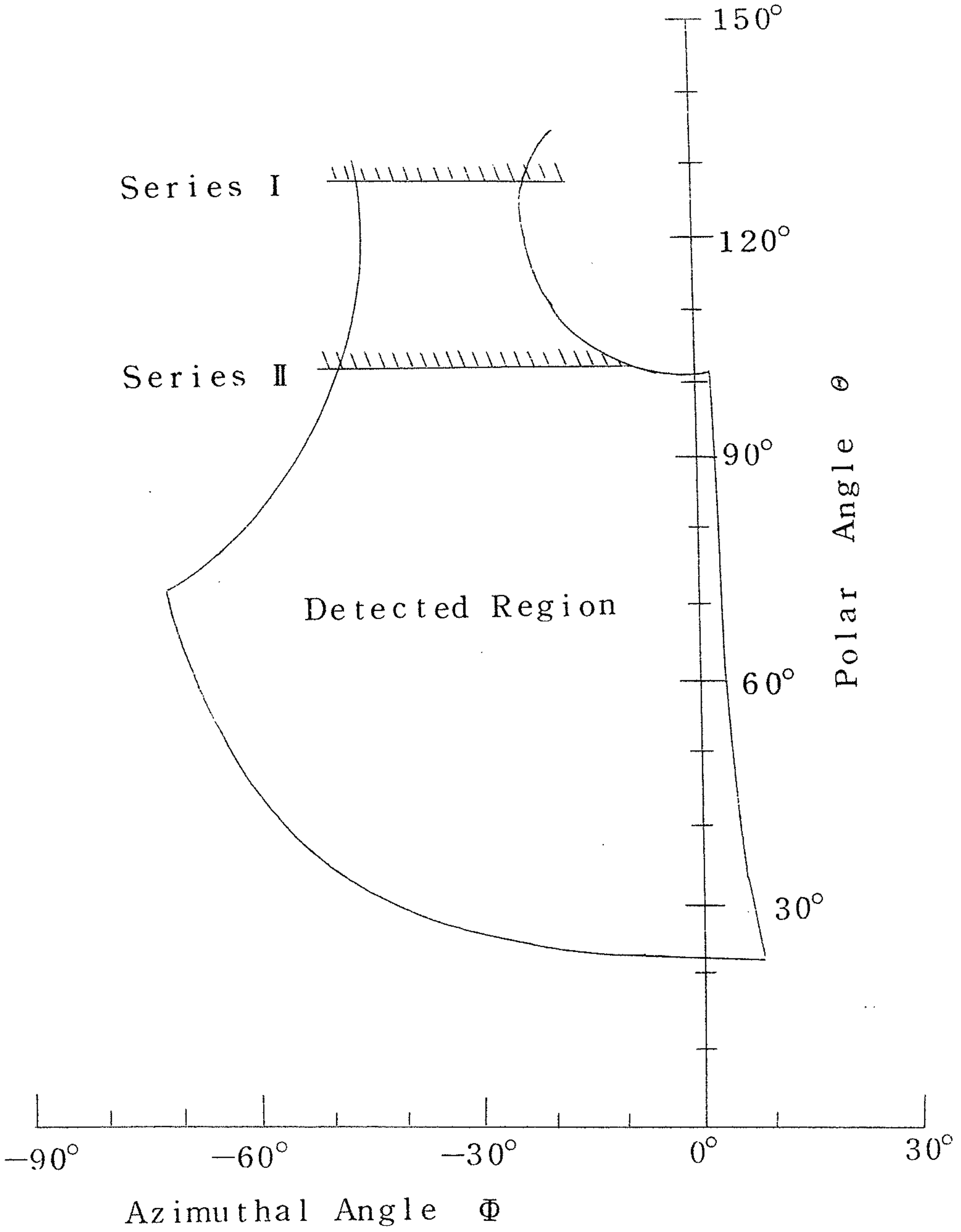

150°
120°
90°
60°
30°
Polar Angle θ
Series I
Series II
Detected Region
−90°
−60°
−30°
0°
30°
Azimuthal Angle Φ

Fig. 3

論　文　審　査　要　旨

本論文は高エネルギー電子による陽子よりの中間子発生に関する実験的研究の報告であつて，6章及び附録の2章より成る。

著者は先づ問題の歴史的，理論的考察をまとめ，次に本実験研究を計画し，又実験諸元の決定に至つた理由を論じている。電子による此の種の反応は仮想光子を通じて行なわれるもので核子や中間子の電磁構造の研究或いは電子反応の過程そのものの研究として重要なものであるが，反応の断面積は非常に小さい。特に陽子よるの中間子発生では中性中間子発生と正荷電中間子発生とを区別するために，同時計数法をとる必要があるが，之は測定を一層困難なものとするため従来信頼に価するデータがなかつた。

著者は中性中間子発生の微分断面積を測定することにより，核子のアイソベクター，フォームファクター及び電子反応の過程に対する知見を得たのであるが，実験は東京大学の750 Mev電子ジクロトロンを用いて行なわれた。測定の方法としては散乱電子の運動量弁別により中間子発生を確かめ，更に之と反跳陽子との同時計数をとることにより，中性中間子発生のみを測定した。

実験の過程において特に注目に価するのは予備実験として電子の陽子による弾性散乱を詳細に測定したことで，これにより本実験の信頼度は著しく高まつたと考えられる。結果の解析においては本反応は非常に稀なものであるだけに誤計数の解析を慎重に行ない，電子の大角度制動輻射反応及び荷電中間子発生反応等を除いた結果として，陽子よりの中性中間子発生の微分断面積を得ている。$(1.0 \pm 0.6) \times 10^{-34} cm^2$ /Mev・ster。

電子反応による中間子発生の理論としてはFubini，Nambu，Wataghinによる分散理論的取扱が最も典型的であるが，本論文の結果は，之ら理論値の約1／3に相当し，著者は此の差は現在の理論的取扱中の問題点を示すものであろうと結論している。

本実験研究は従来信頼に足るデータの乏しい電子反応の分野に貴重なデータを与えたものであり，価値あるものと判断される。

依つて学位論文に価するものと認める。

最終試験は昭和41年2月21日原子核理学専攻の試験委員並びに他教官立合のもとに施行された。主論文，電子による陽子よりの中間子発生の研究に関しては，その物理的意義，実験の方法或いはその解析に関する質疑応答を通じて，本人は論文の内容に関する正しい理解と充分なる研究能力とを有することが判定された。

又併せて，本人は関連学科目である原子核論・高エネルギー物理学に関しても合格の能力を有することが認められた。外国語に関しては，主論文は英文をもつて記されており，又独語に関しても研究遂行上必要なる読力を有することが認められる。従つて合格と判定する。